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Cluster Evolution, Regional Innovation Systems and Knowledge Bases

The Development and Transformation of the ICT Cluster in Southern Sweden

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Roman Martin and Michaela Trippl

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JEL codes: O33, O38, B52

Keywords: Cluster evolution, knowledge bases, regional innovation systems, innovation policy, ICT, New Media, Sweden

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Introduction

Over the past two decades, a vast body of literature on clusters has enhanced our understanding of the positive effects of spatial concentrations of firms operating in the same or in related industries. Recently, a shift from static towards more dynamic perspectives that seek to explain the long-term development and transformation of clusters has taken place (Lorenzen, 2005; Bergman, 2008; Isaksen, 2011; Martin and Sunley, 2011). Inspired by advances in evolutionary economic geography, new cluster life cycle approaches have emerged (see, for instance, Menzel and Fornahl, 2010; Ter Wal and Boschma, 2011). Their main focus is on the micro dynamics (Fornahl et al, 2015), emphasizing in particular characteristics and dynamics of firms, their capabilities and networks. Whilst these approaches have many merits, they have also come under criticism for the limited attention given to place-specific factors and for underappreciating the role played by the configuration and transformation of regional innovation systems (RIS), knowledge bases and policy actions in shaping long-term cluster development (see, for instance, Fornahl et al, 2015; Trippl et al, 2015).

This paper aims to redress the neglect of these factors. We contribute to the literature on long-term cluster development by exploring both conceptually and empirically how cluster evolution is shaped by knowledge base specificities of RIS and policy actions. Special attention is devoted to the question whether regional diversity in knowledge bases and their combination are beneficial to the long-term development of clusters. This idea is in line with recent conceptual and empirical work that suggests that diverse but related economic activities and knowledge specializations are conducive to regional growth and adaptability (Asheim et al, 2011a). The framework proposed in this paper puts due emphasis on the role played by RIS configurations, changes in the knowledge infrastructure, the transformation of organisational and institutional support structures and policy actions in promoting cluster change through facilitating shifts in and combinations of knowledge bases.

The empirical part of the paper examines these issues for the ICT cluster located in Scania, Sweden's most Southern province. Based on an analysis of employment data and face-to-face interviews with firms and other actors, we analyse the cluster's development over time. Since its emergence in the early 1980s, the cluster has undergone several phases. After a period of strong growth, it entered a phase of decline and transformation, followed by a new growth phase. The paper addresses the following research questions.

- How did knowledge-base specificities of Scania's RIS and RIS changes affect the rise, growth and renewal of the ICT cluster?
- How did policy actions aiming at the diversification of the region's knowledge infrastructure and the reconfiguration of the organisational and institutional support structure influence the long-term development of the cluster?

The remainder of this paper is organized as follows. Section 2 establishes the conceptual framework that connects long-term cluster development to the architecture and transformation of RIS, their knowledge base specificities and proactive policy approaches. Section 3 contains the empirical part of the paper. We analyse the birth, growth and transformation of the ICT cluster in the Swedish province of Scania. Section 4 summarizes the main findings and draws some conclusions.

Conceptual Framework and Literature Review

Clusters have become a key concept for scholars and policy makers dealing with regional innovation and growth. While the term 'cluster' was coined by Michael Porter (1990, 1998), the intellectual origins of the concept refer back to Marshall's (1920) early work on industrial districts and ideas developed by economic geographers ever since. Nowadays, clusters have become a central part of regional development strategies in many parts of the world, and notwithstanding a number of critical evaluations (e.g. Martin and Sunley, 2003; Asheim et al, 2006), the notion of clusters is widely used in economic geography, regional economics and related disciplines.

In recent years, there has been a growing academic and policy interest into the question of how clusters evolve over time (see, for instance, Lorenzen, 2005; Bergman, 2008; Isaksen, 2011). Various scholars have seized on the notion of 'cluster life cycles', which is based on the idea that cluster evolution follows a certain life cycle with sequential phases of emergence, growth, maturity, decline and possibly renewal (Bergman, 2008; Menzel and Fornahl, 2010; Martin and Sunley, 2011). Models of the cluster life cycles are inspired by basic product life cycle theory (Levitte, 1965; Vernon, 1966; Cox, 1967) and later studies on industry life cycles (Audretsch and Feldman, 1996; Klepper, 1997).

The literature provides different approaches of cluster life cycles (Pouder and St. John, 1996; Iammarino and McCann, 2006; Maskell and Malmberg, 2007; for an overview see, for instance, Trippl et al, 2015). Over the past few years, new life cycle models have emerged, which are heavily inspired by recent theoretical advances in evolutionary economic geography (Fornahl et al, 2015). In the model suggested by Ter Wal and Boschma (2011, p. 929) clusters "co-evolve with the industry to which they adhere, with the (variety of) capabilities of firms in that industry, and with the industry-wide knowledge network of which they are part." Menzel and Fornahl (2010) argue that key factors that drive cluster dynamics are technological convergence, firm heterogeneity and learning processes. The new life cycle models have in common that they do not consider clusters as being homogeneous entities. Cluster evolution and change are seen as being influenced by the interplay between heterogeneous agents. The new life cycle models thus focus on micro dynamics and highlight the role played by heterogeneity of firm capabilities, localized learning processes (which may result in a reduction of heterogeneity) and openness or rigidities in firm networks to explain the transition from one stage of the life cycle to another but also why come clusters renew themselves while others decline (Trippl et al, 2015).

It is far beyond the scope of this paper to provide a critical appraisal of the different versions of life cycles that are discussed in the contemporary literature (for a thorough review and discussion of the literature, see for instance Bergman, 2008; Fornahl et al, 2015; Hervas-Oliver et al, 2015; Trippl et al, 2015). A main line of criticism passed on cluster life cycle approaches relates to their search for one general path or pattern of cluster evolution and the under-appreciation of context specific factors that may influence the long-term development of clusters. As Fornahl et al (2015, p. 2) in their review of the recent literature on cluster life cycles put it: '… the theoretical contributions describe quite general dynamics, from which single clusters, due to their specific context, most probably deviate'.

In this paper we are mainly concerned with the neglect of *regional* context specificity, i.e., the limited appreciation given to the role played by the wider regional environment in which clusters are embedded, knowledge base specificities of the RIS and proactive policy actions in shaping long-term cluster development and change. The next section seeks to establish a conceptual framework for overcoming these weaknesses of the cluster life cycle models.

Regional Innovation Systems, Knowledge Base Specificities and Cluster Development

Several scholars have argued that the evolution of industries and clusters cannot be fully understood without taking regional context-specific factors into consideration (see, for instance, Saxenian, 1994; Storper, 2009; Trippl and Otto, 2009). As noted above, evolutionary approaches and the new generation of cluster life cycles, however, pay little attention to the place specificity of cluster evolution.

RIS configurations and cluster evolution

The RIS concept provides an advanced framework for identifying and analysing place-specific innovation-related characteristics that are assumed to influence cluster evolution. It devotes attention to the industrial structure and the knowledge infrastructure, knowledge bases, policy and support organizations and institutional configurations prevailing in the region and it sheds light on the importance of local knowledge exchange as well as linkages to non-local knowledge sources. The region is considered as a crucial level at which innovation is generated through knowledge connections, clusters and the cross-fertilizing effects of research and other organisations (Asheim and Gertler, 2005).

Conceptual and empirical work on the relation between cluster evolution and RIS configurations has elucidated why and under what conditions clusters take certain trajectories, sharpening our view of the regional context-specific nature of cluster development. RIS characteristics such as the presence of other industries in the region (degree of industrial diversity and related variety), the quality of the knowledge infrastructure, availability of finance, a pool of skilled workers, dense communication networks, policy actions and region-specific institutions (Prevezer, 2001; Leibovitz, 2004; Trippl and Otto, 2009; Hassink, 2010; Isaksen and Trippl, 2014; Boschma, 2015) have been identified as key factors that assert an influence on the emergence of clusters and the trajectories they take.

Knowledge base specificities of RIS and cluster development

We extend the perspective raised above by emphasising the role played by knowledge base specificities of RIS and clusters. This enables us to add more clarity regarding which specific RIS elements and characteristics matter for long-term cluster development. The differentiated knowledge base approach draws attention to the type of knowledge that is critical for innovation (Asheim and Gertler, 2005). The concept distinguishes between analytical, synthetic and symbolic knowledge bases and argues that they differ enormously with respect to the rationale for knowledge creation, the use of new knowledge and the key actors involved (Asheim et al, 2011a). An analytical knowledge base is dominant in firms and clusters where innovation is driven by basic research. Firms invest heavily in intramural R&D but rely also on knowledge generated by universities and other research organisations. Innovation in synthetic firms or clusters is based on the use and new combination of existing knowledge and learning by doing, using and interacting. Knowledge sourcing tends to occur through linkages to customers and suppliers or mobility of employees as well as through knowledge exchange with providers of applied research. A symbolic knowledge base prevails in firms or clusters where innovation is devoted to the creation of aesthetic value and images. Symbolic knowledge displays a high degree of context specificity. Consequently, local connections between partners with a similar socio-cultural background constitute the dominant pattern of knowledge sourcing.

Building upon the conceptual advance offered by the knowledge base approach provides the foundation for establishing greater clarity and specification of the types of RIS elements and policy approaches that may be conducive to the evolution of clusters (Table 1). In line with previous work (Asheim and Gertler, 2005; Isaksen and Karlsen, 2011; Martin et al, 2011; Martin and Trippl, 2014) we argue that firms and clusters that rely on different knowledge bases require particular research and education infrastructures, support organisations, institutional set-ups and policy approaches.

Table 1: RIS elements and policy approaches targeting firms and clusters with different knowledge bases

Knowledge Base	Knowledge infrastructure and support structure of the RIS: Key organisations	Policy approaches
Analytical	• HEIs in fields of natural and formal sciences (chemistry, physics, mathematics, etc.) • Research facilities; • Science and technology parks; • Technology brokers and transfer agencies	• Investment in basic research, big science projects & large scale research facilities; • Support of top research milieus & centres of excellence; • Promotion of university-industry partnerships
Synthetic	• HEIs in engineering based fields and applied sciences (mechanical and electrical engineering, etc.); • Polytechnic schools and technical colleges with focus on applied sciences • Non-R&D-based business services	• Investment in applied research; • Promotion of inter-firm collaboration and user-producer partnerships; • Schemes for life-long learning and worker participation in innovation
Symbolic	• HEIs in creative and arts based fields (architecture and design, visual & performing arts, humanities, etc.); • Cultural and creative infrastructure (theatres, concert halls, exhibitions, etc.); • Business incubators and meeting places	• Investments in cultural and creative infrastructure; • Promotion of project-based collaboration for innovation; • Business support and coaching for start-ups and SMEs; • Promotion of people climate (diversity, tolerance, quality of place)

Source: own compilation based on Martin and Trippl (2014)

Arguably, the presence of knowledge-base specific RIS elements exerts a strong influence on the emergence and evolution of analytic, synthetic and symbolic clusters. Specific RIS architectures and RIS changes (particularly the creation of new or adaptation of existing knowledge organisations and support structures that are fine-tuned to the knowledge-base specificities of clusters) through strategic policy approaches thus matter for the rise, development and successful renewal of clusters. This does not mean, however, that the role of policy is necessarily confined to promoting the development of one knowledge base (the region's or cluster's dominating one) only. As argued below, cluster evolution may also benefit from combinations of knowledge bases and policy strategies that actively promote such processes.

Combinations of knowledge bases, diversified RIS and cluster evolution

The argumentation outlined above on the nexus between RIS, knowledge bases and cluster evolution can be further enriched by exploring shifts in and combinations of knowledge bases in the course of cluster development. Such a perspective is in line with recent insights into the importance of related variety and combinatorial knowledge base dynamics for innovation, the emergence of new regional industrial growth paths and the successful adaption of mature ones to changes in markets and technologies (Asheim et al, 2011a; Manniche, 2012; Strambach and Klement, 2012; Boschma, 2015). RIS that exhibit or nurture different types of knowledge bases and provide adequate knowledge infrastructures and organisational and institutional support structures for their integration offer good conditions for cluster renewal and transformation. Consequently, policies aiming at the promotion of diversity in the institutional set-up and the creation of knowledge and support organisations that facilitate the integration of different types of knowledge bases may positively affect the long-term development of clusters. This idea is well in line with public policy strategies advocated by modern policy concepts such as the constructing regional advantage approach that emphasises the promotion of cross-sectorial knowledge flows and proactive policy intervention consisting of concerted, long-term efforts at system, organizational and institutional levels for long term cluster evolution (Asheim et al, 2011a, 2013).

Our framework is thus designed to capture regional context specific factors by considering RIS architectures and changes, their knowledge base specificities and combinatorial knowledge dynamics. Adopting this framework does not mean that we neglect the impact of firm strategies on cluster evolution. Nor do we deny the role played by industry dynamics, technological developments and other influences and changes at higher spatial scales for long-term cluster development. However, how clusters "respond" to such extra-regional influences is mediated by the factors stressed in our framework.

Empirical Analysis: Evolution of the ICT cluster in Scania

This section analyses the evolution of the ICT cluster in Scania, the southernmost province of Sweden. Particular attention is devoted to identifying the factors that lead to cluster emergence, growth and transformation. A key aim is to explore the role of RIS characteristics, knowledge base specificities and policy actions in the different phases.

Swedish employment register data[1] is used to outline the general evolution of the cluster. To understand the factors behind cluster evolution, document studies are combined with in-depth interviews with key individuals and firm representatives. The empirical analysis draws upon

[1] The ICT manufacturing and service sectors proposed by the OECD (2002, 2011) are matched with the Swedish standard industrial classification system (SNI), which structure the Swedish register data. The period 1990-2010 could be covered with reliable data by matching the sector codes SNI92 and SNI2002. Due to major changes in sector codes between SNI2002 and SNI2007, it was not possible to extend the time series beyond year 2010. The cluster's development since 2010 is, however, well covered through qualitative interviews with firms and regional stakeholders. Employment in ICT wholesales sectors were excluded from the analysis.

37 interviews with firm representatives conducted in 2008-2009 and is further informed by 10 interviews with policy makers, industry experts, cluster managers and business angels carried out in 2012-2013.

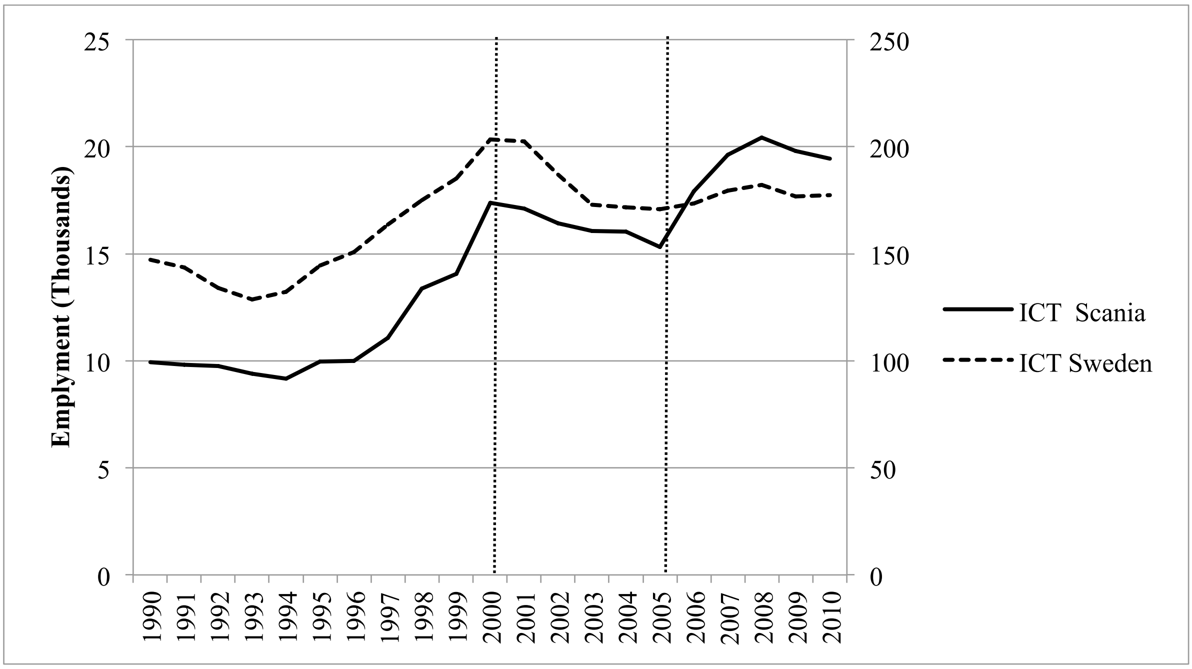

Figure 1: ICT sector employment growth in Scania and Sweden, 1000 employees, years 1990-2010
Source: Based on Statistics Sweden register data. SNI2002 sector codes: 30010, 30020, 31300, 32100, 32200, 32300, 33200, 33300, 64201, 64202, 64203, 72100, 72210, 72220, 72300, 72400, 72500, 72600, 73102.

A first picture of the overall development of the cluster can be gained from ICT sector employment data (see figure 1). Changes in employment over the last decades reveal several phases of cluster evolution: from emergence prior to year 1990, to a phase of growth in the 1990s, a phase of decline and transformation in the early 2000s, and a new phase of growth from year 2005 onwards. While the cluster engaged around 10.000 persons in year 1990, employment almost doubled to a number of 17.400 in year 2000. Layoffs and a drop in employment to 15.000 characterized the subsequent period until year 2005. But then again, the cluster regained its growth momentum and the number of employees reached around 20.000 in year 2008. While the data for 2009 and 2010 show a small negative trend in employment, results from interviews suggest a more positive trend from 2010 onwards, in particular for employment in ICT subsectors related to software development and design.

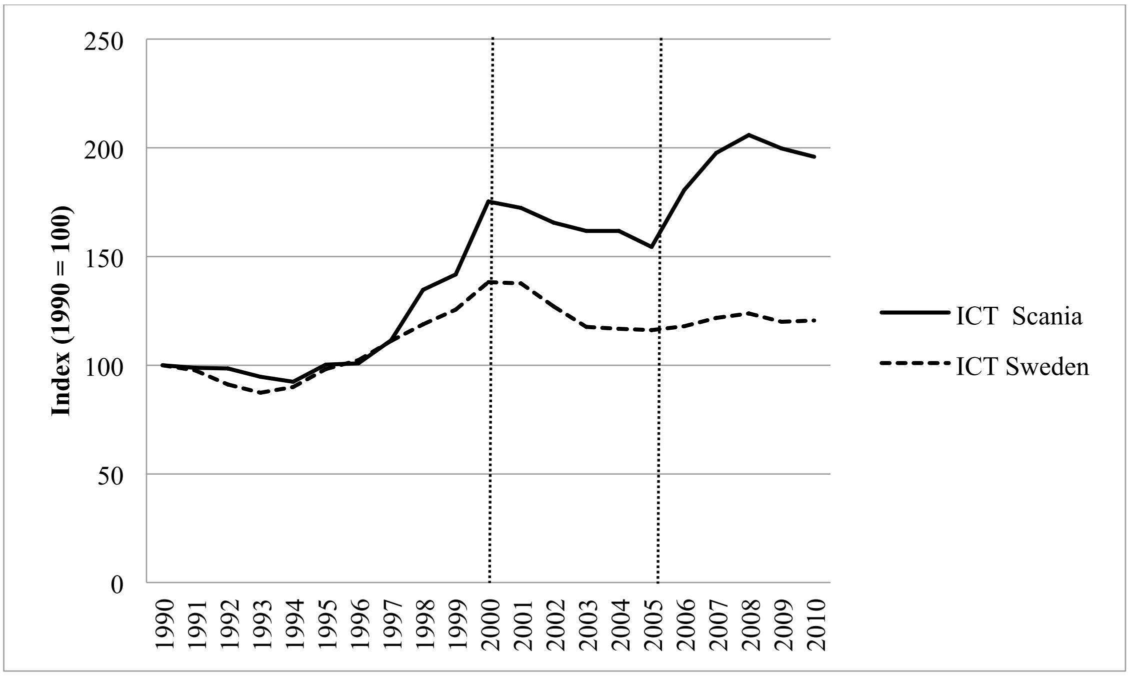

Figure 2: ICT sector employment growth in Scania and Sweden, index (1990 = 100), years 1990-2010
Source: Based on Statistics Sweden register data. SNI2002 sector codes: 30010, 30020, 31300, 32100, 32200, 32300, 33200, 33300, 64201, 64202, 64203, 72100, 72210, 72220, 72300, 72400, 72500, 72600, 73102.

When comparing regional with national ICT employment, it becomes apparent that the cluster developed more dynamically than the national industry (see figure 2). While regional and national employment growth rates were similar in the early 1990s, the cluster displayed considerably higher growth rates during the late 1990s. Both the regional and the national ICT industry faced comparable decline rates in the aftermath of the global IT crisis in year 2000. But then again, while the national ICT industry recovered only at slow rates, the regional cluster took off rapidly and employment reached a level that surpassed the pre-crisis phase.

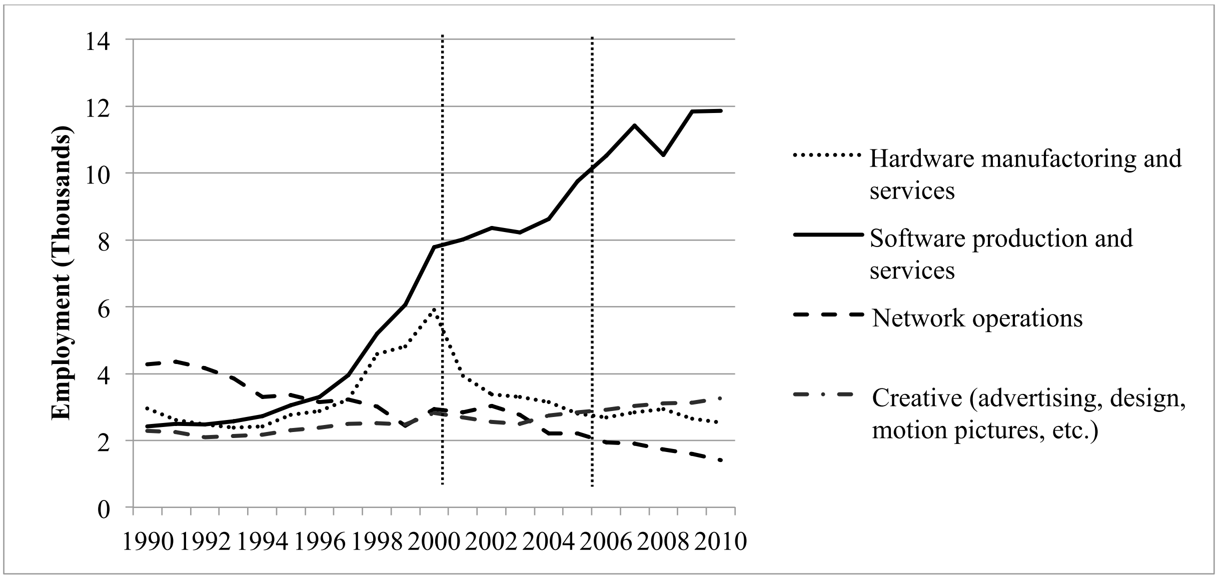

Figure 3: Development of the ICT cluster in Scania, number of employees in subsectors, years 1990-2010
Source: Based on Statistics Sweden register data. SNI2002 sector codes: Hardware: 30010, 30020, 31300, 32100, 32200, 32300, 33200, 33300, 72100, 72500; Software: 72210, 72220, 72300, 72400; Network operations: 64201, 64202, 64203; Creative: 74401, 74871, 74872, 92110, 92120, 92130, 22320, 22330.

In order to understand the changing nature of the cluster, the total ICT sector employment can be divided into subsectors, which reveals a shift in activities over time (see figure 3). In the early 1990s, most employment occurred in the area of network operations, covering the development and maintenance of telecommunication infrastructure. The focus soon shifted to hardware and software manufacturing and services, playing a similarly important role until the year 2000. While software development may include symbolic activities (e.g. computer games), hardware development is typically dominated by analytical knowledge. From year 2000 onwards, hardware development lost its significance and the cluster is increasingly driven by software publishing, consultancy and supply activities, including design oriented software development. At the same time, employment in creative sectors such as advertising, graphical design, and motion pictures and video production, grew continuously. Accordingly, the changes in sectorial employment indicate a shift from analytical and synthetic towards more and more symbolic activities in the cluster.

The employment data presented above illustrates the overall development of the cluster and delimits several phases of cluster evolution. To reach a deeper understanding of the factors triggering cluster development, including dimensions such as the role of regional policy and knowledge base specificities of the RIS, intensive research methods are applied for the following case study.

Emergence Phase (1980-1990)

The emergence of the ICT cluster in Scania can be traced back to the year 1983, when the telecommunication company Ericsson decided to locate an R&D department in the region. Together with the Swedish Telecom, Ericsson has been the dominant player in the national ICT sector and one of the largest companies in Sweden. Ericsson can be regarded as typical example of a large, (multi-)national firm with strong science- and engineering-based capabilities. It follows mostly a closed model of innovation, and, for collaborative innovation, carefully selects partners on a global scale (Chaminade and De Fuentes, 2012, Isaksen and Karlsen, 2013). In the early 1980s, Ericsson expanded into the newly emerging mobile communication business with the development of the first generation of mobile phones. At that time, mobile communication was a promising new business area and led to a strategic re-orientation and expansion of Ericsson.

The dynamic development of the mobile communication sector was accompanied by a growing demand for skilled labour, in particular for scientists and engineers with an educational background in radio communication. The labour market around Ericsson's main research centre in Stockholm could not supply enough scientists and engineers to keep up with the company's growth, and the second research centre in Gävle, a small town north of Stockholm, lacked a university with a suitable profile. As a result, the company's management board decided to establish a new R&D centre in a region possessing the appropriate setting for research in mobile communication, for which a strong university was regarded as decisive.

"*The decision taken by Ericsson management was that you can't grow the R&D centre in Gävle because they have no university. I mean, number one is: university, university and university!*" (industry expert)

Southern Sweden, hosting the country's largest university with a strong engineering faculty (Lund University Faculty of Engineering, LTH), provided the appropriate regional setting for the company's expansion. When establishing the new research centre in Lund, Ericsson relocated its best scientists in radio technology to Scania. Around the same time, LTH appointed a new professor in applied electronics, who had been research manager at Ericsson before. In his new role as professor, he was able to steer higher education and basic research at LTH towards areas that were related to mobile communication. While LTH had always been strong in research on electronic engineering, the new focus on commercial radio was to the clear benefit of Ericsson.

"*It was only because we wanted to have a strong university… and university research in areas which were important for us. It does not mean that they needed to do what we say, but in the areas we felt were important.*" (firm representative)

The collaboration between the company and Lund University was further eased by the establishment of Sweden's first science park (IDEON), formed in 1983 by joint initiative of Lund University, the regional government and Ericsson, who became the first tenant company. Located in close proximity to Lund University, the science park soon developed into a key support organisation for science and engineering-based firms in the region (Bengtsson and Lind, 2004; Benneworth et al, 2009).

The presence of a strong analytical and synthetic knowledge base with Lund University/LTH as core element of the knowledge infrastructure of the RIS has thus been eminently important for the emergence of the ICT cluster. It proved to be a key factor for attracting Ericsson, which established an R&D centre in the region. The reorientation of parts of LTH's research and teaching towards ICT and mobile communication and the foundation of IDEON have led to an adaption and further strengthening of the knowledge infrastructure and the organisational support structure and buttressed the analytical and synthetic knowledge base of the RIS, benefitting the dynamic growth of the cluster with Ericsson as lead firm surrounded by a number of small consulting and supplying companies that were established around that time.

Growth phase (1990-2000)

In the 1990s, the ICT cluster went through a phase of rapid growth driven by Ericsson and its activities in mobile communication, and a close cooperation between Ericsson, LTH, and national research funding agencies.

During the rapid growth of the cluster, national funding agencies (in particular VINNOVA's predecessors STU and NUTEK) played an important role in driving innovation through financing university research (Arnold et al, 2008). The funding agencies had the practice of widely investing in potentially interesting research projects, and these projects were selected in a bottom-up process through a dialogue with stakeholders from industry and academia. Moreover and equally based on signals from stakeholders, long-term research funding programmes were established in strategically important technological areas. Ericsson was very early lobbying for public research funding on ICT, and a distinct national research programme on ICT was set up in the early 1990s. Regular informal contacts took place between Ericsson and the national research funding agencies, and over time, the dialogue became more and more intense, with Ericsson sharing road maps of future developments and discussing unresolved research problems with both the research funding agencies and Lund University.

The public funding did not only lead to relevant research outcomes, but also triggered an expansion of doctoral education at LTH and the supply with skilled scientists and engineers. This has further strengthened the analytical and synthetic knowledge bases of Scania's RIS, which supported Ericsson and other cluster firms to cope with new technological challenges, i.e., the shift from analogue to digital communication between mobile phones. Developing the digital technology posed new challenges to the scientists and engineers, in particular how to convert and code speech, by using as little network bandwidth as possible while reaching a high level of speech quality. Experimental mathematics was required to address these technical challenges, coupled with evaluation and testing procedures. Even though formalized and science-based knowledge was key to innovation, many technical problems could hardly be foreseen through theoretical research (for example, that the same coding algorithm that worked well for European languages made Asian languages incomprehensible). The solutions eventually found were typically based on a combination of theoretical research and practical engineering effort, demonstrating the need for analytical as well as synthetic knowledge in the innovation process.

Decline and transformation phase (2000-2005)

In the early 2000s, a number of events caused a disruption of the existing business structure, and the ICT cluster went through a phase of decline and transformation.

The year 2000 marked the peak of the overheating IT economy and the bursting of the global internet bubble constituted a major shock to the cluster. Falling stock prices and job losses affected all telecommunications companies worldwide, and Ericsson, still the dominant player in the cluster, shed hundreds of jobs. Moreover, technological progress created new challenges to the cluster. The existing mobile network infrastructure could not keep up with the growing demand for data transmission capacity, so that a new mobile communication standard became necessary. This new standard was developed in an international coordination process, and network operators in Europe were offered to acquire licences through a series of auctions. These auctions were designed to increase pressure on potential bidders by offering fewer licenses than the number of operators likely to bid. This created a difficult situation for the mobile operators, because a loss of the auction would imply an exclusion from the next major phase of mobile phone technology. In this process, Ericsson took high risks and incurred large debts, which additionally fuelled the job losses in the R&D centre in Lund. Another incidence that affected the cluster was the changing political agenda of the national research funding agencies (from 2001 onwards VINNOVA). Even though ICT was still among the national priority areas, research in fields that were perceived as particularly important for mobile communication, namely silicon and embedded software, did not receive the anticipated funding. As a result, research at LTH turned towards fields that were less related to mobile communication, which impaired the potential for cooperation and knowledge exchange between Ericsson, other cluster firms and the university.

Even though the early 2000s constituted a phase of crisis for the existing business structure, the period also laid the ground for a transformation of the cluster towards a new growth path. This transformation process of the cluster was characterised by a growing importance of the symbolic knowledge base and its combination with the established analytical and synthetic ones. The creation of new RIS structures and other policy actions have essentially facilitated the renewal of the ICT cluster in Scania.

At that time, local and regional policy makers were looking for possibilities to develop new business activities in Malmö, the capital city of the region. They agreed upon a strategy to support creative and cultural industries in Malmö. The idea was to build on existing competences that were available in the RIS, and to promote new business development around the theme of New Media. New Media comprises activities such as film and TV, digital arts and design, computer games software, and various graphical applications for computers and mobile phones. In this business area, innovation involves a combination of hard- and software technology with creative media content, which requires not only analytical and synthetic knowledge, but also a high degree of symbolic knowledge (Manovich, 2001; Lievrouw and Livingstone, 2002; Martin and Moodysson, 2011). The new regional development strategy covered a range of initiatives to strengthen the region's symbolic knowledge base. The old harbour area in Malmö was transformed into a modern housing and office area to serve as location for new creative businesses. The local university college in Malmö (founded in the year 1998) formed the key element of the knowledge infrastructure and began to focus parts of its education activities on digital arts and design, and established a new study programme on New Media. Furthermore, in 2003 a business incubator (Malmö Incubator, MINC) was established to support entrepreneurship and new firm formation in New Media. In addition to creating new RIS knowledge and support organisations, the policy strategy also comprised the establishment of a network initiative (Media Evolution, ME) that proactively sought to promote a combination of knowledge bases by stimulating linkages and knowledge flows between established ICT and emerging new media activities in the RIS (Asheim et al, 2015; Martin et al, 2015).

New growth phase (2005-today)

From the year 2005 onwards, the regional ICT cluster experienced a new phase of growth, characterized by more diverse actor constellations and a growing importance of symbolic knowledge activities.

The new phase of cluster growth was closely related to technological advancements in the mobile communication sector. The most significant development is the widespread use of smartphones, offering a whole range of new services including web browsers, media players, digital cameras, and navigation. Higher network capacity made mobile data transmission fast and reliable, and technological progress made hardware components smaller and more powerful, so that the distinction between telephony and computing became more and more blurred. Increasing competition led to new global value chains, with a small number of multinational companies developing processors and other hardware components for all major telecommunication companies worldwide. As a result, research and development on hardware, for which analytical knowledge is decisive, is increasingly carried out in other parts of the world. Operating systems, a previously important business field, are now offered almost for free in form of open-source software, and are hence equally losing in importance. The new growth areas are the development of software applications, graphical user interfaces and related services for mobile devices. These products and services require competencies that are only partly based on analytical- and synthetic knowledge, such as programming and mathematics, and much more on symbolic knowledge related to creativity, arts and design.

Unlike other RIS with less diversified knowledge infrastructures, support structures and a narrow knowledge base (for a study on the ICT cluster in Northern Denmark, see Østergaard and Park, 2015), Southern Sweden had favourable conditions to cope with these new challenges, due to a strong analytical and synthetic knowledge base in Lund and a growing symbolic knowledge base in Malmö.

Rather than leading to major job losses and long-term decline, several rounds of layoffs at Ericsson spurred new firm formation:

"Layoffs have been good for the region, because they have led to entrepreneurship and creativity." (firm representative)

The ICT cluster recovered quickly from the crisis through entrepreneurial activities and the formation of new firms that could combine technical features with design and media content. Examples for such companies are The Astonishing Tribe (TAT) creating graphical user interfaces for mobile devices and Polar Rose developing facial recognition software. These companies gain their competitive advantage by combining analytical and synthetic skills with symbolic knowledge (Martin and Moodysson, 2011). The combination of different types of knowledge bases can be observed at the firm level, but also for the cluster as a whole, leading to new actor constellations in the cluster. Recently, the dynamic development of the cluster has also attracted ICT companies from outside the region (such as Sony Mobile, Huawei mobile, RIM, ARM), which seek to be located in close geographical proximity to the new area of innovation.

"We have gaming companies, advertisement companies, publishers, local newspapers, app developers, media technology companies, pure IT companies, they are all important in the value chain. That is why you cannot say any more whether it is ICT or whether it is media, it is all going together." (policy maker)

Today, the cluster is characterized by a growing importance of smaller firms and start-ups, a rise in importance of symbolic knowledge, and the emergence of open forms of innovation. A shift has taken place from a closed innovation model typically employed by large and science- and engineering-based firms, which has been characterizing the early evolution of the cluster, towards intensive collaboration and knowledge exchange between firms in the RIS, which is characteristic for the new growth phase. Local collaboration and knowledge circulation is a typical feature of clusters that rely on symbolic knowledge (Asheim et al, 2011b; Martin and Moodysson, 2013).

The RIS and policies approaches were key factors, enabling the cluster to transform and recover from the crisis. The creation of a new research centre for digital media (MEDEA) at Malmö University has further enhanced the knowledge infrastructure and provided new opportunities for knowledge exchange. Another new RIS element is the recently established large business park Media Evolution City (MEC) in Malmö that houses many of the new media firms. Finally, the continuation and widening of the network initiative has essentially facilitated the new growth phase of the cluster. Although it has been renamed several times (Media Meeting Place Malmö (MMM), Moving Media Southern Sweden (MMSS) and Media Evolution (ME)) its general approach has been unaltered. Based on the principles of platform policies it is providing support for integrating different types of knowledge bases and stimulating networking and knowledge flows between different subsectors of the ICT cluster.

Even though the recent evolution of the cluster is characterised by new firm constellations, several attempts were made to revitalise the science- and engineering-based business structure that dominated the cluster previously. A case in point is the network initiative Mobile Heights, founded by Ericsson, TeliaSonera, LTH, and the regional government to strengthen science-based entrepreneurship and innovation in mobile communication. Another example is the research institute MAPCI (financed by Sony Mobile Communication, Ericsson, Lund University and the regional government) with the mission to conduct research on cloud computing and mobile communication and to collaborate with the local industry. Even though these initiatives have become visible parts of the knowledge infrastructure and organisational support structure of the RIS, the cluster continues to develop into a direction where innovation is less driven by scientific advancements, and more by symbolic knowledge and its combination with analytical and synthetic knowledge.

Table 2: RIS elements and policy approaches in the evolution of the ICT cluster

Phases of cluster evolution	**Cluster actors**	**Knowledge infrastructure and organisational support structure of RIS**	**Policy actions and approaches**
Analytical and synthetic knowledge base			
Emergence (1980-1990)	• Establishment of Ericsson's R&D centre in Lund	• LU/LTH (research & higher education in the field of mobile communication) • IDEON Science Park	• Establishment of science park by regional policy makers, LU & Ericsson
Growth (1990-2000)	• Ericsson as lead firm surrounded by supplying & consulting companies		• National funding programme on ICT • University-industry-government relations
Growing importance of symbolic knowledge base and combination with analytical & synthetic ones			
Transformation (2000-2005)	• Restructuring & layoffs at Ericsson • New firm formation and entrepreneurship by former employees	• LU/LTH shifting focus away from mobile comm. • Malmö University/K3 (research & higher education in the fields of design, media & communication) • Business incubator (MINC)	• Platform policies to combine competences in mobile communication and media: network initiatives M-Town, MMM • Establishment of business incubator
New Growth (2005-present)	• Cluster is driven by a large number of design oriented firms • Foreign ICT firms locate development offices to southern Sweden	• Research & innovation centre for digital media (MEDEA) • Business park (MEC) • Research institute (MAPCI)	• Continuation platform policies: network initiatives MMMS & ME • Establishment business park • Network initiative (Mobile Heights) • Establishment of new research institute (MAPCI) jointly run by regional policy, academia and industry

Source: own compilation

Table 2 summarizes our main findings. The empirical analysis of the evolution of the ICT cluster in Scania has highlighted that the presence of a strong university has been central for the emergence of the cluster as it provided the region with an analytical and synthetic knowledge base that was required for research and innovation in mobile communication. This led to the settlement of a large anchoring firm in the region. The subsequent growth of the cluster was carried by a close relationship and intense collaboration between industry, academia and government, where publicly funded research at the university played an important role. The crisis of the cluster in the early 2000s had multiple reasons, most of which were out of control of the firms in the cluster, such as the growth and burst of the IT bubble, and a new strategic orientation of national research funding agencies. Nevertheless, an important precondition for a new phase of cluster growth came by initiative of regional policy makers, namely a stronger symbolic knowledge base that has been reinforced through a regional innovation strategy aimed at creative industries. This enabled the cluster to transform and, in that way, to cope with global changes in the mobile communication industry, where creative media content plays a more and more vital role. The new phase of cluster growth is driven by new actor constellations and economic activities that bring together traditional ICT with creative media, and thereby combine analytical, synthetic and symbolic knowledge bases in the innovation process.

Our empirical study has clearly revealed that the birth, evolution and transformation of Scania's ICT cluster cannot be understood without analysing regional place specific factors, i.e., knowledge base specificities of the RIS, changes of the knowledge infrastructure, the transformation of the organisational support structure and policy actions. The emergence and growth of the cluster was inextricably linked to the presence and further development of an analytical and synthetic knowledge base of the RIS and respective knowledge infrastructures and organisational support structures. The later phases of cluster development (phases of transformation and new growth) were essentially facilitated by strengthening the RIS's symbolic knowledge base and by combining it with the existing analytical and synthetic ones. Local, regional and national policy makers played a vital role in these processes by funding research activities, promoting the transformation and diversification of the RIS through establishing new support organizations, and a long term network initiative. The latter is particularly interesting. Designed as a platform policy, it stimulated combinations of knowledge bases and linkages between different but related sub-sectors, enabling the successful recovery of the ICT cluster and its further growth.

Conclusions

This paper sought to contribute to research on long-term cluster evolution by examining both conceptually and empirically how cluster development is shaped by regional innovation systems (RIS), their knowledge base specificities and policy actions. By doing so, we redress the neglect of regional context specific factors by current accounts of cluster life cycle models. We also highlighted that regional diversity in knowledge bases and their combination are beneficial to the long-term development of clusters. This idea is in line with recent scholarly work that has shown that diverse but related economic activities and knowledge specializations are conducive to regional growth and adaptability (Asheim et al, 2011a). The framework proposed in this paper puts due emphasis on the role played by RIS configurations, diversification of the knowledge infrastructure, transformation of organisational and institutional support structures and policy actions in promoting cluster change through facilitating shifts in and combinations of knowledge bases.

Our empirical study of the evolution of Scania's ICT cluster has demonstrated that cluster evolution cannot be understood without considering the knowledge-base specificities of the RIS, its transformation, and policy actions. As shown in this paper, firm level dynamics, which are at the centre of new cluster life cycle approaches, are only one among many forces at work. Firms that are at the forefront of technological development may struggle with the next technological paradigm. But even if the dominating businesses lose competitiveness, clusters can renew themselves by drawing on the wider range of knowledge bases available in the RIS, including skills that were made redundant in a phase of crisis, and competencies that were built up in other parts of the regional economy. RIS that bring together diverse economic activities and combine analytical, synthetic and symbolic knowledge bases can provide favourable conditions for cluster renewal and in that way secure regional resilience and long term economic growth. Regional context specific factors thus matter and long-term proactive policy efforts can essentially shape cluster development by strengthening the support structure and enabling a combination of different types of knowledge bases.

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